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DEPARTMENT OF COMMERCE -- BUREAU OF MINES

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BY

J. J. FORBES AND M. J. ANKENY

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SOME PHASES OF COAL-MINE VENTILATION[1]

By J. J. Forbes[2] and M. J. Ankeny[3]

IMPORTANCE OF VENTILATION

Ventilation is the most important safety factor in the production of coal because on it depends the safety, health, and efficiency of those who work underground. Without adequate and efficient means of supplying fresh air to the working faces, mining could not have advanced as it has. The extent of the workings, the increase in mechanization, and the increasing use of electricity are largely responsible for changes in methods of ventialtion.

Ventilation in the early days of coal mining was accomplished by means of a natural draft, created principally by a difference in the weights of columns of air between the intake and return openings. Later the furnace was introduced for the purpose of increasing the quantity of air in circulation. Mines continued to become larger, their output increased, men were employed in greater numbers, and more fresh coal surfaces were exposed. Coal beds near the surface, and practically free from explosive gas became exhausted, and deeper beds that liberated methane were opened as development advanced. Mechanical ventilation became necessary and was first accomplished by disc-type steam-driven fans. The old-fashioned steam-driven disc fan has generally been supplanted by the powerful electrically operated centrifugal fans in use at modern coal mines. In order to be secure against gas explosions and provide ample fresh air for persons employed in large coal mines, air must be conducted through the mine to all working places and to all other unsealed parts of the mine in sufficient quantities to dilute and render harmless all dangerous and noxious gases.

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DANGERS OF INADEQUATE VENTILATION

Lack of adequate and efficient ventilation is the primary cause of gas ignitions in coal mines. Gas explosions occur only when there is an accumulation of gas mixed in suitable proportion with air. Explosive gas does not accumulate in properly ventilated mines. The secondary causes of gas ignitions are: (1) Improper installation, maintenance, or use of electrical equipment; (2) Use of open lights; (3) Use of nonpermissible explosive or the improper use of permissible explosives; (4) misuse of safety lamps; (5) matches and smoking; (6) mine fires. Until recently, open lights ranked second as a cause of explosions.

It is a matter of record[4] that from July 1, 1927, to June 30, 1928, there were 29 ignitions of explosive gas, costing the lives of 341 men in coal mines of the United States. Of these explosions, 14 were of electrical origin, 10 were caused by open lights, 3 were from explosives, and 2 were from unknown causes.

RESPONSIBILITY FOR PROPER VENTILATION

In order to have proper ventilation and promote health and safety, most coal-mining States have provided laws which require the operator to employ a competent and practical overseer, usually called the mine foreman or mine manager, for every mine. He is required by law to have a license or certificate, and such certificate is supposed to be sufficient evidence of his competency. The foreman is charged with the duty of keeping a careful watch over the ventilating apparatus, airways, entries, and all other parts of the mine to see that the provisions of the law are complied with. As the foreman is held legally responsible for the ventilation of the mine and as the maintenance of ventilation is the most important part of his job, he should be thoroughly conversant with the good and bad practices pertinent to coal-mine ventilation.

EFFECT OF OUTBURSTS OF GAS

Coal mines are usually classed as gassy and nongassy or as open-light mines and closed-light mines by State inspection departments or State laws. Some States permit individual mines to be divided into open-light sections and closed-light sections. As a rule a different set of laws from those applied to gassy mines is provided for so-called nongassy mines or nongassy sections of mines. Men who are not considered competent to serve as foremen in gassy mines are legally permitted to serve as foremen in so-called nongassy mines. More or less explosive gas is generated in all coal mines; in mines where gas has never been detected with a flame safety lamp it is not uncommon suddenly to encounter methane in the advance workings, sometimes when it is too late to make provision for taking care of it. Frequently there is a group of mines operating adjacent to each other in the same coal bed with the same thickness of overburden, yet one is classed as gassy and the other as nongassy. At the mines which are classed as nongassy or which are operating with open lights few if any precautions are taken o safeguard against a gas ignition in the event that an unexpected gas feeder is pened up or an accumulation of gas on top of a caved area is swept into the work-ng places by a fall or by derangement of the ventilating current.

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[4] Harrington, D., Mine Explosions in the United States During the Fiscal Year Ending June 30, 1928: Information Circular 6085, Bureau of Mines, 1928, 4 pp.

The fact that explosions often occur in mines that are not recognized or dmitted to be gassy is borne out by records. The so-called nongassy mine which ives off small quantities of methane is more dangerous than the definitely gassy ine where precautions are usually taken against possible accumulations or ig-itions of gas.

RECOMMENDATIONS OF THE BUREAU OF MINES

The Mine Safety Board of the United States Bureau of Mines has made the ollowing decision (No. 1) relating to miners' lamps in coal mines[5]:

> "(a) In all coal mines the portable lamps for illumination be permissible, portable, electric mine lamps; and also
>
> "(b) In places where fire damp or black damp is liable to be encountered, a permissible magnetically-locked flame safety lamp for gas detection, or equivalent permissible device, be supplied to at least one experienced employee in each such place; and
>
> "(c) Any employee before being supplied with a permissible flame safety lamp be examined by a competent official of the mine to assure the man's ability to detect gas; and
>
> "(d) All coal mines whether classed as nongassy or gassy in any part, be supplied with magnetically-locked, permissible, flame safety lamps, properly maintained and in sufficient number for all inspection purposes."

All coal mines in which inflammable gas in excess of 0.05 per cent can be found by systematic search should be classed as gassy mines; however, in order to be practically secure against gas explosions, all coal mines should be managed, equipped, and ventilated according to the best safe practices recommended for gassy mines.

TYPES AND ARRANGEMENT OF FANS

In order to circulate air through the mine, a difference in pressure must be created between the intake and the return airways. In modern coal mines, this effect is produced by a fan preferably of the centrifugal type, which develops a much higher efficiency than the old and almost obsolete disc-type fan. Some fans are arranged to force air through the mine, others to exhaust it from the mine; during recent years, however, installations of the latter type have been more common. In the best practice the intake air should enter or downcast through the hoist shaft or slope and main haulageroads, and should return or upcast through the air shaft. Fans should be constructed to permit quick reversal of the ventilating currents to meet emergencies due to fires or explosions, and the fan casings should have explosion-relief doors. Fans should be offset from the air shaft or air drift at least 25 feet from the projection of the nearest side so that they will not be damaged by an explosion. Fireproof construction of fans and casings should be required. When new fans are installed they should be of such size and efficiency as to produce the necessary volume of air against the natural resistance of the mine; much forethought should be given to the higher resistances likely to develop in the future life of the mine as the length of the airways increases and the volume requirements, the amount of exposed surface, and the number of men and animals increase[6].

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[5] Mine Safety Board Recommendations of the Bureau of Mines on Certain Questions of Mine Safety: Information Circular 6091, 1928, 12 pp.

Maintenance of Continuous Operation of Fans

Fans should be equipped with some form of warning device to attract the attention of the attendant if it has stopped from power failure or other cause. One method of doing this is to place a make-and-break contact device on the shaft of the fan to open and close an independent electric circuit with each revolution. In this circuit are red incandescent lamps at points where the attendant or outside foreman may observe them at all times. When the fan is running the lamps continue to blink, but when the fan stops, the lights discontinue "blinking" remaining either "on" or "off." Another device which is in use at some mines is an electric bell controlled by a water gauge and float; when the fan stops, the gauge float drops, permitting it to make an electric contact which closes an electric circuit and rings a bell; the bell continues to ring until the fan is restarted or receives attention. There are many other good methods of calling attention to fan stoppage.

Fans should be equipped with a continuous recording device which shows the water gauge of the mine. There should also be a similar device to record the speed of the fan. Foremen and others whose duty it is to help maintain the ventilation of the mine should always observe the water-gauge reading at the fan before making an inspection of the mine. When the recording water gauge shows any material change the mine officials should take extra precautions to ascertain the reason for the alteration.

Fans should be kept in continuous operation while there are men in the mine, and they should have an auxiliary drive, such as a steam engine or gasoline engine. If the fans are electrically driven, a separate source of power should be provided where the mine is known to give off explosive gas. When a fan stops and can not be immediately started, when it is necessary to stop the fan for any reason, or when any major changes are being made in the ventilating system, the men should be immediately removed from the mine.

If a fan is stopped purposely or by accident, all electric power underground should be immediately cut off unless the result of so doing would prevent or seriously handicap escape of the men in the mine. An automatic device for opening main switches on electric circuits leading underground can be easily constructed in any mine machine shop as follows: Weld a piece of circular sheet metal with a one-eighth-inch hole in the center over one of the 6-inch openings of a 4 by 6 by 6 inch iron pipe to the 4-inch end of the T into a hole made in the air duct leading to the fan, and carefully cement the 4-inch end in place with the open 6-inch end of the T pointed downward. A circular 6½-inch sheet-metal plate with a rubber gasket covering one side of it should be provided to fit over the open end of the T. This plate should be of such a weight that the negative pressure on the plate, created by the running of the fan, would be just sufficient to hold it in place over the mouth of the 6-inch hole of the T. Attach a piece of flexible wire to the center of this plate on the inside and pass it through the one-eighth-inch hole in the plate, welded on the top end of the T, to the lever of a low-voltage switch mounted directly above the T. When the fan stops, the negative air pressure on the bottom plate will be relieved; the plate will fall and in so doing pull the flexible wire which operates the low-voltage switch controlling a relay switch in the main power circuit.

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[6] The question of changing fans at certain periods during the development of a mine was discussed by W. A. Weldin and others of the Engineers' Society of Western Pennsylvania. See volume 39 of the Proceedings, 1923, pp.113-114.

Booster and Auxiliary Fans

The booster and auxiliary fans used for a number of years extensively and appropriately in metal mines have been installed in some coal mines. Most of these subsurface installations in coal mines are open to severe criticism because coal mining is attended by dangers from which metal mining, with rare exceptions, is free. The Mine Safety Board of the Bureau of Mines recommends in decision No. 4[7] that

> "Auxiliary fans or blowers should not be used in coal mines as a substitute for methods of regular and continuous coursing of the air to every face of the mine."

Quantity of Air for Ventilation

To conduct the air into and outby from the active working sections of the mine there should be at least three but preferably four, five, six, or more main parallel entries or slopes. The number of main entries required is determined largely by the proposed ultimate size of the mine, size of individual air courses, and quantity of air which is likely to be needed to ventilate the mine. In smooth-lined shafts and air courses the velocity in general should not exceed 1,800 feet per minute; in ordinary rough-ribbed airways it generally should not exceed 900 feet per minute; in main haulageways and manways the velocity should not exceed 600 feet per minute. On the other hand, the velocity of the air current of any one split should not ordinarily be less than 200 feet per minute, and where strata temperatures are high, the velocity required may be much greater than 200 feet per minute; the volume of a regular split should not be less than 10,000 cubic feet per minute in order to dilute and sweep away gases and dusts and provide the men with air that is within the limits of purity for health.

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[7] See reference 5, Page 3

Decision No. 7[8] of the Mine Safety Board of the Bureau of Mines says:

"In the interest of safety, the Bureau of Mines recommends:

"1. That the main intake and main return air currents in mines be in separated shafts, slopes or drifts.

"2. That the main intake shaft lining be of fireproof construction, and that there be a minimum amount of inflammable material in or adjacent to the shaft."

STOPPINGS

Stoppings in breakthroughs between the main intake and return entries or shafts should be substantially built of fireproof material, and they should be "hitched" into ribs and floor composed of soft material. They should be carefully plastered and the ribs, floor, and top in the immediate vicinity of the stopping should also be plastered to prevent leakage. Main entry stoppings should be built of brick, cement block, tile, concrete, or similar material which will make them tight, solid, and incombustible.

Stoppings in breakthroughs on butt or developing entries should be substantially built of fireproof material, preferably brick, cement block, tile, or concrete. Gob stoppings well plastered on one side or brick stoppings laid without mortar but carefully plastered can be made effective. The advantage of using brick stoppings for this purpose is that the brick can be reclaimed on the retreat and used again. Under no circumstances should unplastered gob stoppings or board stoppings be used permanently in developing entries.

Overcasts should be substantial, fireproof, and leakproof. The theory that flimsy overcasts may help to check an explosion by blowing out and relieving the pressure should be given no consideration. The roof above and leading to and from the overcast should be so excavated as to leave an easy curve or incline overhead to create the least possible resistance to the flow of air, and the floor leading to and away from the floor of the overcast also should be a smooth incline.

DOORS

Main ventilating doors should be carefully installed with the frame, preferably of concrete, hitched well into the ribs. The doors should be of steel; if made of timber they should be of two thicknesses of matched boards, one thickness placed diagonally with fire-resistant canvas between. The doors should be so hung as to be self-closing by a suitable system of weights and pulleys or other equally effective means; if they are arranged for mechanical opening and closing, the arrangement should be positive as to keeping the door closed at ordinary times. All principal doors should be so placed that when one door is open, another which has the same effect upon the ventilating current shall be closed and remain closed to prevent any short-circuiting of the air current. No hook or similar device should be placed on any door to hold it open during temporary passage of cars nor should he propping open of doors be allowed. The mine should be planned and developed to liminate doors or at least reduce the number of doors to a minimum.

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[8] See reference 5, Page 3

AIR FLOW IN SPLITS

In order to get a sufficient flow of air in the longest splits in a mine, it is usually necessary to create an artificial resistance in one or more of the shorter splits. This result is accomplished by placing a regulator in the returns of the short splits, provided that such a position will not interfere with the operations in that split. A good type of regulator is a brick or concrete stopping with a rectangular hole that allows plenty of space for the passage of a man and has a horizontal slide to permit close regulation of the air current passing through.

In decision No. 9 the Mine Safety Board of the Bureau of Mines recommends in coal-mine ventilation the following specifications[9] as to unit quantity and quality of air:

> "1. The quantity in cubic feet of pure intake air flowing per minute in any ventilating split shall be at least equal to 100 times the number of men in that split.
>
> "2. The quantity of air entering each unsealed place shall be at least 200 cubic feet per minute and as much more as may be necessary to properly dilute and carry away inflammable or harmful gases which may be present.
>
> "3. The air shall be made to circulate continuously to the face in every unsealed place into which an appreciable amount of methane enters.
>
> "4. The air in any unsealed place shall be considered unfit for men if it shall be found to contain less than 19 per cent oxygen (dry basis), more than 1 per cent carbon dioxide, or a harmful amount of poisonous gas.
>
> "5. If the air in any unsealed place, when sampled or tested in any part of that place not nearer than 4 feet from the face and 10 inches from the roof, shall be found to contain:
>
> > "(a) more than 1½ per cent of inflammable gas, the place shall be considered to be in hazardous condition and require improved ventilation, and
> >
> > "(b) if more than 2½ per cent of inflammable gas is found, the place shall be considered dangerous and only men who have been officially designated to improve the ventilation and are properly protected shall remain in or enter said place.

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[9] See reference 5, Page 3

> "6. If the air in the split which ventilates any group of workings contains more than $1\frac{1}{2}$ per cent of inflammable gas, these workings shall be considered to be in a dangerous condition and only men who have been officially designated to improve the ventilation and are properly protected, shall remain in or enter said workings."

ACTUAL QUANTITY OF AIR TRAVERSING WORKINGS

Too much attention can not be given to the proper maintenance of doors, overcasts, regulators, and stoppings, for here air losses chiefly occur. A large quantity of air going into or out of a mine does not indicate that the mine is well ventilated. The foreman who is interested in the efficacy of his ventilating system should keep a careful check of the total quantity of air measured in the intake and return of each split against the total quantity of air at the last open crosscut in the split to determine the approximate percentage of air lost; he should also check the sum total of the air of the various splits against the total of the intake and the return of the entire mine to ascertain what part of the air entering or leaving the mine is put to actual use.

Only a few States specify where the measurement of the air currents shall be made. Generally, they permit the volume of air entering the mine to be measured at the foot of the shaft or in the entrance of a slope or drift. A good standard practice is to measure the total intake, the intake and return of each split, the air in last crosscut of each entry in a split, and the full return from the mine.

Tests have shown that in 16 Illinois coal mines an average of only 18.6 per cent of the entering air reached the last crosscuts nearest the faces because of leakage at doors, stoppings, overcasts, and through crevices in pillars and roof[10]. Good practice requires that at least 50 per cent of the air entering a mine shall reach the faces; it is possible to get as high as 80 to 85 per cent with good natural conditions and properly built doors, stoppings, and overcasts. It costs money to circulate air through a mine whether this air effectively reaches the working faces or not, and properly constructed stoppings, doors, and overcasts soon pay for themselves in the saving of power.

VENTILATING ROOMS AND ENTRIES

In order properly to ventilate developing rooms and pillar lines it is necessary to deflect the current of air into the rooms to be ventilated by means of light wooden or wooden and canvas curtains. Extreme care should be taken in the construction of deflectors of this type to prevent them from coming in contact with electric wires of any kind and creating a fire hazard. When gas is being given off or likely to be given off at the face, it may be necessary to erect canvas checks or doors in the entry at fairly frequent intervals; as an alternative the check canvas curtains or doors may be placed in the entry between a few of the rooms so as to thus deflect air into the rooms which can be held there by canvas curtains or light doors placed in the room necks. In addition, temporary toppings should be placed in all crosscuts between the first and second rooms and n the last and next to last rooms, excepting the crosscuts nearest the faces in hese rooms; and in definitely gassy mines all room crosscuts but the one nearest he face should be stopped off.

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[10] Williams, R. Y., Mine Ventilation Stoppings, with Especial Reference to Mines in Illinois: Bull. 99, Bureau of Mines, 1915, 30 pp.

Frequently, it is necessary to conduct the air from the last crosscut in ooms and entries to the face by means of a line brattice erected from the outby orner of the crosscut to a point 5 or 6 feet distant from the face. Room stoppings ay be constructed of canvas securely nailed to posts or board frames supported by osts or by boards supported by posts. Line brattices should be constructed of a eavy canvas which preferably has been treated by a fireproofing material. Wherever racticable the brattice should be placed in a room or entry so that on the intake ide of the canvas the area is smaller than the outlet side, thus providing a higher velocity of air to sweep the face free of generating gas. Where smooth roof and loor conditions exist, a line brattice may be stretched on posts, or preferably ailed to a substantial frame, but where very rough and irregular roof conditions revail, holes should be bored in the roof at the high points, plugs inserted, and he canvas nailed to the plugs. It is important that temporary entry and room toppings and line brattices be substantially built and made as air-tight as possible. Failure of these devices, due to accident, may quickly create a very serious xplosion hazard at the face.

The use of small portable fans or blower fans in connection with canvas ubing or pipes for the purpose of ventilating headings, rooms, or narrow workings hat are without crosscuts is not recommended. Where absolutely necessary to use hese dangerous expedients, as in tunneling work, their installation as well as heir operation should be very carefully safeguarded if gas explosions and fires re to be avoided.

VENTILATING WORKED-OUT AREAS

None of the several general methods of trying to ventilate worked-out areas can be onsidered even reasonably effective. One method is to cause the air to sweep along he edge of the breakline, so as to put a pressure on the caved area and dilute and arry away gas that may come off the caved area. Although this method generally rovides fresh air for men working the pillars or stumps and ordinarily keeps the orking places free from gas, the danger of a gas explosion is ever-present. In he event of an interruption of the ventilating current -- due to failure of the an to operate, to a door left open, or to blocking the air current by a fall in he airway -- pressure on the caved area is relieved, thus permitting the explosive as to come from the falls into the working places. A large fall back in the caved rea may also force the gas out into the working places.

A method of ventilating caved areas, in use at many mines, is to pass some ir over the caved regions into the return airways of adjacent sets of entries. In eveloping rooms occasional rooms are driven through the barrier pillar into the return of the adjacent set of entries and a regulator is placed in the room near the point where it connects with this return. When the retreat work has passed one of these rooms which has been holed through, the regulator can be opened to permit some air to flow through. With this method of ventilation, a current of air is continually passing over the caved area and possibly carrying away explosive gas as it is being given off; however, this method can be used only in those mines in which the engineering "layout" is favorable to its use when sufficient air is supplied to the producing workings to permit losing a small proportion over the extracted areas. Air samples should be taken at these bleeders from time to time to determine the amount of air required to be passed through the regulators to keep percentage of explosive gas within safe limits.

Decision No. 6 of the Mine Safety Board of the Bureau of Mines recommends that:[11]

> "All entries, rooms, panels, or sections that can not be kept well ventilated throughout or can not be inspected regularly and thoroughly, or that are not being used for coursing the air, travel, haulage, or the extraction of coal, be sealed by strong fireproof stoppings."

When the difficulty of efficiently ventilating live advancing workings is considered, it seems beyond the realms of possibility to keep inaccessible caved abandoned regions even reasonably free of accumulations of methane; hence the safest procedure with worked areas is undoubtedly to seal them "by strong fireproof stoppings" as recommended by Bureau of Mines Safety Board Decision No. 10, quoted above.

REMOVAL OF GAS ACCUMULATIONS

Every mine should be kept free of standing gas in all parts except those sections which are effectively sealed. Any accumulation of standing gas should be removed as soon as possible after its discovery; until the gas has been removed no one should be allowed in the gassy portion of the mine except the men engaged in the removal of the gas under the direct supervision of the foreman. Before attempting to remove gas, all power circuits should be cut off in the portion of the mine affected and an ample quantity of air provided to keep the mixture, as it passes into the return, below the explosion point.

DEFINITIONS FOR VENTILATION PRACTICE

Decision No. 8 of the Mine Safety Board of the Bureau of Mines recommends[12] that in coal-mine ventilation the following definitions be used:

> "1. The term "intake air" and the term "return air" without qualifying adjectives shall be used only to define mechanical movement of the air respectively in an inward and outward direction with reference to the mine as a whole or to any one group of workings.

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[11] See reference 5, Page 3

[12] See reference 5, Page 3

"2. When health and safety are concerned, the term "pure intake air" shall mean:

> "(a) Air which has not passed through or by any active workings, and (or)
>
> "(b) Air which has not passed through or by any inactive workings, unless these are effectively sealed, and
>
> "(c) Air which is free from poisonous gas and by analysis contains not less than 20 per cent oxygen (dry basis) and not over 0.05 per cent inflammable gas."

Records show that the improper installation and use of electrical equipment in other than pure intake air have become the most prolific source of ignition of gas and dust in initiating mine explosions. Of the 31 explosions investigated by the Bureau of Mines during the fiscal year ended June 30, 1928[13] 14 ignitions were caused by electricity and 282 men were killed in the resultant explosions. In order to use electricity with relative safety in other than pure intake air it is absolutely necessary to carry out certain specifications, among them the following:

1. The installation of trolley wires and the use of trolley locomotives should be permitted in pure intake air only.

2. Feed lines for mining machines should be covered with good insulation and supported on insulated hangers on the opposite side of the entry from the side on which men are permitted to travel.

3. The "nipping" or tramming of mining machines by sliding the nips along bare wires in other than pure intake air should not be permitted. Permissible junction boxes should be provided for the purpose of connecting machines and drill cables to the power feeder circuits. When junction boxes are provided at proper intervals along feed lines, tramming the mining machines from place to place by sliding a trolley nip along bare wires is unnecessary.

4. Animal haulage or permissible storage-battery locomotives only should be used for gathering coal in other than pure intake air.

5. All electrical equipment used in other than pure intake air fresh from the outside should be of the permissible type approved for safety by the U. S. Bureau of Mines. Such equipment should be inspected regularly and maintained in a permissible condition at all times.

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[13] See reference 4, Page 2

INSPECTION FOR GAS

In order that the foreman may know that his mine is being maintained in a safe and healthy condition he sould give much thought to the matter of inspections. He should build up his organization by carefully selecting competent men to act as section foremen and firebosses. In addition to the legal requirements for section foremen and firebosses, these men should be capable and energetic men who have had considerable practical experience in gassy mines. They should be physically fit, particularly with respect to good eyesight, and should be proficient in the knowledge of limitations, use, and care of the flame safety lamp.

The fireboss, section foreman, and mine foreman should arrange the time of their daily visits to the working places while the men are in the mine so that the lapse of time between visits of mine officials is about evenly divided. Good mining practice demands that working places be inspected at frequent intervals and a proper record should be made of such inspections. A good rule for mine officials to adopt is to visit each working place at two-hour intervals, and more often if necessary. At some operations it is the practice to require the fireboss to perform other duties than those concerning safety, for which he is intended; in only too many mines the fireboss must build doors, measure deadwork or yardage, report condition of coal content of places, aid in timbering or in blasting coal, and so forth. The fireboss should not be required to perform duties other than looking after the safety of the men in his section of the mine. He should be required to leave a date mark and his initial at the face of every place examined and he should sign his report book at the end of each examination of his section and not at the end of the shift only.

There is too much laxity in the supervision of the night shift and during the periods when shifts are being changed. This is proved by the fact that many of the coal mines explosions of the recent past have occurred during these periods. From January 9 to June 20, 1928, there were six explosions which occurred during the night shift, during the period while the shift was being changed, or shortly before or after change of shifts. The time of ignition was as follows: 9:30 p.m., 7:45 a.m., 6:30 p.m., 7:45 p.m., 1:30 a.m., and 4:07 p.m. These six disasters killed 257 men.

MEASURING AIR VOLUME AND DETECTING GAS

The mine foreman should know how to measure air and should be conversant with the instruments for the detection of gas in order to perform properly the inspections necessary to determine whether the mine is being maintained in a safe condition.

The Anemometer

Many foremen when measuring air with the anemometer suspend it at arms length in the center of an entry and hold it in this stationary position until the measurement is completed. This method may be useful in making comparative measurements, but it is very likely to give incorrect information as to the quantity of air that is actually flowing past the point where the measurement is being taken. A good quick method which is accurate to about 10 or 20 per cent is to traverse the area of the airway being measured. Select a place in the airway which is free from eddy currents and reasonably straight for a distance of about 100 feet both ways from the point at which the measurement is being taken. Start at the upper left-hand corner of the entry and move the anemometer down along the rib to the lower left-hand corner; move it slowly, steadily, and continuously from that point toward the right-hand rib for about one-fourth the width of the entry and then up toward the roof; then to the center and down to the floor; from this point over to about one-fourth the distance from the right-hand rib, and then up to the top, over to the right-hand rib, and down along the right rib to the floor. This procedure will give a good average reading of the velocity. The anemometer should be permitted to run at least one minute; longer time than this would tend to make the reading considerably more accurate. The correction factor of the anemometer should always be applied.

The Psychrometer

The use of the psychrometer is valuable in determining the amount of moisture being taken into and carried out of the mine by the ventilating current. It can be used to determine the percentage of saturation of the mine atmosphere at any point in the mine and also the temperature of the air in which men are working. Every foreman should be familiar with this instrument and with the meaning of the data obtainable by it.

The Flame Safety Lamp

The flame safety lamp is a comparatively simple device for quickly detecting the presence of explosive gas or a deficiency of oxygen in a mine atmosphere. It is the foreman's closest companion because many foremen carry it wherever they go while in the mine. It may be used to advantage also by section foremen, firebosses, shot firers, machine-runners, and all others whose duty it is to inspect or examine for explosive gas. A permissible lamp approved by the U. S. Bureau of Mines, properly assembled and tested out in the hands of a competent person who thoroughly understands the use of the lamp, is absolutely safe. During the last 20 years several hundred men have lost their lives because a few men have used flame safety lamps in ways that made the lamps dangerous. The bureau does not know of any explosion caused by a properly assembled, permissible flame safety lamp.

In 1917 an explosion in a coal mine in Colorado caused the death of 121 men. The firebosses of this mine were accustomed to report a mine free of gas if not more than a five-eighths-inch gas cap showed in their lamps. This practice in itself was dangerous because a five-eighths-inch cap meant that the atmosphere contained approximately 3 per cent of gas and that a slight change or derangement in ventilation might increase the gas to 5.5 per cent, making it explosive. The safety inspector, a trusted man, carried a key-locked lamp, the only one used in the mine. The lamp was found taken apart near his body and 22 matches were found in his clothing. Undoubtedly his lamp flame "went out;" then he took the lamp apart and tried to re-light it with a match. Instead he ignited the gas and thus caused a terrific explosion which killed every man and completely wrecked the mine.

It frequently happens that the foreman has a key-locked lamp, while the other underofficials are required to carry a permissible lamp. A mine foreman should by all means have the right kind of lamp. He should not permit in the mine any flame safety lamps that are not magnetically locked. The Bureau of Mines does not approve any flame safety lamp unless it is equipped with internal igniter and magnetic lock.

The flame safety lamp has its uses and serves its purposes well, but it also has its limitations. The lowest percentage of gas which it will detect depends upon the observer. Some persons claim that they can detect as little gas as 1 per cent; others claim that 1½ per cent is the least that can be detected. It is not unusual to see a fireboss or foreman come out of the mine to sign his report book, go to his locker or cupboard and get his spectacles, and then proceed to sign the book. It is impracticable for a man who can not see well enough to sign the report book without glasses to detect small quantities of gas without them, and practically no consideration is given to the fact that a man may be color-blind and unable to see the nonluminous flame of a gas cap. These facts are pointed out to show that there is a definite need for something to supplement the use of the flame safety lamp if not to supplant it.

HOW METHANE ACCUMULATES

Any conscientious mine foreman should know that when there is as little as 1½ or 2 per cent of gas in any split in the mine he should recognize this as a dangerous condition and take steps to remedy it immediately by supplying more air to the split. It should interest him just as much to know that he had 1 per cent, 0.5 per cent, or 0.2 per cent. For example: 0.5 per cent of gas in a split through which 40,000 cubic feet of air per minute passes would mean that there would be 200 cubic feet of methane emitted in the split per minute; if the ventilation were disrupted for one hour there would be an accumulation of 12,000 cubic feet of methane which, if mixed with air in explosive proportions, would create 240,000 cubic feet of fire damp — enough to fill a 6 by 10 foot entry 4,000 feet long, or eight 200-foot rooms 30 feet wide by 5 feet high, full of explosive gas. It is obvious that some means of detecting the presence of methane in quantities lower than can be detected by a flame safety lamp would aid greatly in making coal mines safer from explosions.

In addition to the common practice of foremen and fire-bosses' examination with safety lamps, some system of daily or at least weekly sampling and analysis of return air currents should be in effect. Comparison of these analyses gives a daily or weekly check on the freedom from gas of those portions of the mine ventilated. For safety, the proportion of methane in return airways should be kept less than 0.5 per cent. However, the quantity of air necessary to keep the percentage of methane to 0.5 per cent in splits should not exceed 20,000 cubic feet of air per minute. When more than this quantity would be required to keep the methane content below 0.5 per cent, the work on that split should be slowed down or some other method devised to aid in removal of the methane.

DETERMINING THE METHANE IN RETURNS

The amount of methane in the return airways of splits may be determined by collecting air samples and analyzing them on the outside of the mine, or by making determinations with the Burrell methane indicator inside the mine at the point where it is desired to know the methane content. This methane indicator is correct to 0.2 per cent and requires 5 to 8 minutes to make a determination. After a little practice it can be operated by anyone with ordinary intelligence. An electrical methane indicating device recently approved by the Bureau of Mines utilizes the effect due to burning gas on the surface of a filament which causes a change in resistance on a Wheatstone bridge, and an increase of temperature due to the combustion of the gas on the surface of the heated wire. This wire is connected with a set of fixed and variable resistancesin an electrical circuit. Any change in the resistance of the wire causes a current to flow through a meter in the Wheatstone bridge circuit and the resultant movement over a scale graduated in per cent methane gives a direct indication of the amount of this gas present in the atmosphere to an accuracy of 0.2 per cent. Tests can be made with this device almost as quickly as with a flame safety lamp.

The mine foreman, section foreman, and firebosses before making their inspection of the mine should observe the water-gauge reading at the fan. An unusually low water gauge may indicate that the air has been short-circuited by a door left open, or that a fall has destroyed a stopping or overcast. An unusually high water gauge may indicate that a large fall in the airway is obstructing the flow of air; however, this procedure is not always reliable. They should make a test for gas in all working places, all places adjacent to working places, returns from splits, and tops of falls as far up into the gobs as possible. They should observe the direction of flow of air and should make frequent trips through return airways to see that they are free from falls.

CONCLUSIONS

The following conclusions may be drawn from the foregoing discussion:

1. Ventilation is the most important operation in the production of coal in connection with the safety, health, and efficiency of men employed.

2. There are very few coal mines, if any, where methane may not be found by systematic search.

3. Mines classed as nongassy, hence usually where proper precautions are not taken, are more hazardous than gassy mines where most of the known precautions are observed.

4. Permissible portable electric lamps and permissible flame safety lamps should be used in all coal mines.

5. A fan of proper size to meet the requirements of the mine should be installed on the surface.

6. Generally it is preferable to use an exhaust-type fan, so installed as to allow of reversing the direction of the air quickly if desired.

7. Auxiliary means of driving a fan should be provided, especially where it is known that any considerable quantity of methane is given off by any section of the mine.

8. If the fan stops, the men should be removed from the mine and generally all electric power should be cut off.

9. Fans should be equipped with an automatic warning device to attract the attention of the fan attendant or other responsible person if the fan stops.

10. Fans should also be equipped with a continuous recording device which shows either the water gauge or speed of the fan or both.

11. Booster or auxiliary fans should not be used for supplying air to working faces.

12. Preferably there should be three or more main entries to conduct the air into and out of the mine.

13. Stoppings in main and developing entries should be constructed of fireproof material and should be practically air-tight and substantially constructed.

14. The main intake and return air currents in mines should be in separate shafts, slopes, or drifts.

15. Overcasts should be substantially built of fireproof material; they should also be maintained free of leaks.

16. Ventilating doors should be carefully installed and maintained and careful provision should be taken against possible fires started by contact of electric wires with the timber or other inflammable material in doors or doorframes.

17. The quantity (cubic feet) of pure intake air flowing (per minute) in any ventilating split should be at least 100 times the number of men in that split, but the minimum quantity in regular splits should not in general be below 10,000 cubic feet per minute.

18. The air should be measured at the main intake, main return, the intake and return of each split, and the last open crosscut of each entry.

19. The air entering a split should be coursed to sweep the working faces by means of doors, stoppings, deflectors, and line brattice.

20. Small portable or blower fans should not be used except possibly for exploratory work in faults or in driving rock tunnels. Even in such cases they are dangerous, and their installation and use should be very carefully safeguarded.

21. Where possible, gob areas should be ventilated by passing air over the top of them.

22. Abandoned sections should be effectively sealed.

23. Every mine should be kept free of standing gas except those sections which are properly sealed.

24. A body of explosive gas should be removed by capable men under the direct supervision of the mine foreman when all other men are out of the mine and all electric power is shut off.

25. The installation of trolley wires and the use of trolley locomotives should be permitted in pure intake air only.

26. Tramming a mining machine from place to place by sliding a trolley nip along bare wires in other than pure intake air is dangerous. practice. Permissible junction boxes should be installed for the purpose of connecting mining machine cables and drill cables to the power feed circuit in all places except in pure intake air fresh from the outside.

27. Power feed circuits installed in air currents which have passed through or by any active workings should be properly guarded, covered with good insulation, and supported on hangers on the opposite side of the entry from which men travel.

28. Electric pumps, drills, mining machines, gathering locomotives, telephones, and all other electrical equipment which is operated in a current of air other than pure intake air should be of the permissible type approved for safety by the U. S. Bureau of Mines, and utmost care should be taken that such equipment is kept at all times in essentially perfect repair.

29. Section foremen and firebosses should be physically and mentally competent, and they should be proficient in the use and care of the flame safety lamp and in knowledge of the limitations of the flame safety lamp.

30. Firebosses should not be required or permitted to act in the dual capacity of mine official and mine laborer.

31. In measuring air, care should be taken to get a dependably accurate measurement.. The slipshod methods of measuring air which are in common use are responsible for much of the danger that exists in our coal mines.

32. Some means of indicating methane in percentages lower than can be detected by a flame safety lamp should be employed, such as the use of the Burrell Indicator or the Orsatt apparatus.

33. Analysis of split returns should be made daily or at least weekly.

34. The gas content in a split return should not be allowed to go above 0.5 per cent.

35. Water-gauge readings at a fan should always be observed before making an inspection of a mine; however, the water-gauge data should be regarded as but

one of numerous types of information which should be obtained daily to allow of assurance of reasonably safe conditions in the mine.

36. All working places should be examined for fire damp as many times during the working shift as possible by mine officials, and all persons making such inspections should chalk their initials and date mark on a permanent surface near to the face.